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# PRECISION FARMING TECHNOLOGIES ADOPTION: A STATE OF THE ART SURVEY

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**Abstract**

This study aims to identify the state of the art of scientific publications related to Precision Farming (PF). In particular, we sought to identify studies focused on understanding which factors may influence farmers' decision to adopt PF technologies. Thus, we systematically reviewed the researched content to quantitatively and qualitatively map the results. The searched databases included *Web of Sciences* and *Scopus*. The descriptors used included *precision agriculture* AND *adoption* and *precision farming* AND *adoption*, tabulated in the StArt tool and Microsoft Excel. Among the 55 studies selected for bibliometric analysis, 26 were eligible to undergo content analysis. Results show that the number of studies on the topic has grown each year, peaking in 2020, with 17 published studies. Then, there was a slight decline in 2021, with 14 studies. Furthermore, we identified two major authorship and co-authorship networks. One with 18 researchers and the other with 20, evidencing the sharing of researchers' knowledge and experiences to understand farmers' perceptions regarding PF adoption. After the analysis, we pointed out two large research groups dedicated to studying PF adoption, which combined have 33 researchers and after reading through the full texts we found that only three articles used some theory as a basis for understanding PF adoption.

**Keywords**: Adoption; Literature Review; Precision Agriculture; Technology.



**Resumo**

Este estudo tem por objetivo identificar o estado da arte das publicações científicas relacionadas ao tema Agricultura de Precisão (AP). Mais especificamente, buscou-se identificar os estudos focados em entender quais fatores podem influenciar na decisão dos agricultores em adotar as tecnologias de AP. Para tanto, foi elaborada uma revisão sistemática do conteúdo pesquisado, no intuito de mapear quantitativa e qualitativamente os resultados. Foram realizadas buscas nas bases de dados *Web of Sciences* e *Scopus*, utilizando os descritores *precision agriculture* AND *adoption* e *precicion farming* AND *adoption*, tabulados na ferramenta StArt e Microsoft Excel. Dos 55 artigos selecionados para a análise bibliométrica, 26 foram qualificados para serem submetidos à análise de conteúdo. Os resultados mostram que o número de estudos sobre o tema cresceu a cada ano, tendo seu pico em 2020, quando foram publicados 17 artigos e posteriormente uma pequena queda em 2021, com 14 artigos publicados. Além disso, foram identificadas duas grandes redes de autoria e coautoria, uma com 18 pesquisadores e outra com 20, evidenciando o compartilhamento dos conhecimentos e experiências dos pesquisadores para entender as percepções dos agricultores sobre a adoção de AP. Após a análise, apontamos dois grandes grupos de pesquisa dedicados ao estudo da adoção de AP, que somados contam com 33 pesquisadores e após a leitura dos textos completos constatamos que apenas três artigos utilizaram alguma teoria como base para a compreensão da adoção de AP.

**Palavras-chave**: Adoção; Agricultura de Precisão; Revisão de literatura; Tecnologia.

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## INTRODUCTION

Precision Farming (PF), or information-based management of agricultural production systems, is currently considered more than just using new technologies in agriculture. It is also an information revolution, minimizing losses and maximizing financial gains. It can be used as a farm-wide management strategy based on measuring a set of variables involving the entire production system, providing high-level results to the farmer.

In order to optimize production, PF comprises combined technologies, including machines, sensors, information systems, and computerized management. They consider crop variability. It emerged, in the 1980s, with newly available technologies for applying inputs at rates that varied according to the crop needs. At that time, soil sampling results, aerial photographs, and crop reconnaissance provided insight into crops' spatial variability.

Currently, PF provides several benefits, including the adaptation of production inputs within the crop, which enables the rural producer to optimize productivity, minimize losses, and increase financial gains. Moreover, it promotes environmental benefits and improves food supply sustainability.



Regardless of the benefits PF provides for agricultural enterprises, adoption is still slow and quite heterogeneous in several countries. At the moment, exist three distinct types of significant challenges in PF adoption: (i) socioeconomic barriers, (ii) agronomic barriers, and (iii) technological barriers.

Socioeconomic barriers comprise issues related to costs, the producer's age, and level of education. The introduction of new technologies requires a series of changes in agricultural practices. Furthermore, it requires high investments and additional costs with maintenance and training, for example.

Agronomic barriers include the lack of basic information, inadequate sampling and measuring procedures, and the lack of training and qualified technical assistance for agronomists and farmers. Technological barriers involve the equipment, software, and especially the connectivity between them. In addition, the lack of qualification of the professionals using this equipment impairs the quality of the information generated since the equipment can be incorrectly operated.

Such barriers must be removed for a better acceptance and distribution of PF technology. The practices specific to the site are an essential aspect of the agricultural system. They offer potential benefits in different important points of agriculture such as profitability, productivity, sustainability, crop quality, food security, life quality on the farm, and rural economic development.

Given that it is an innovation, farmers' perceptions regarding PF adoption are quite heterogeneous. Even though producers are increasingly willing to use new technologies, many have difficulties understanding PF and implementing it in their crops.

Over the past ten years, there has been a significant advance in PF technologies. However, there is still a mismatch between the available technology and the technology effectively used in decision-making, possibly resulting from the lack of knowledge regarding the procedures to be adopted.

Given this scenario, this study aims to characterize the state of the art of scientific publications that investigate farmers' determinants of PF adoption to identify the evolution and content of studies on the subject in recent years. This analysis will emphasize the qualitative and quantitative results obtained from the systematic review.

This study is divided into three sections: the first is this introduction; the second presents the methodological procedures; and the third includes the results and discussions of the analyses, followed by the conclusions and bibliographical references.

## LITERARUTE REVIEW



The adoption of new technologies is fundamental in the context of modern agriculture, which seeks to optimize production and reduce environmental impact (CIRANI; MORAES, 2011). It is driven by the capacity to gather information related to the profitability of agricultural operations (REIS et al., 2020). In Precision Farming (PF), technological innovation involves the use of machines and equipment, agricultural pesticides, fertilizers, biotechnology (CIRANI; MORAES, 2011).

In this way, PF consists of a set of technologies used alone, or together (TEY; BRINDAL, 2012), to enable a management system that considers the spatial variability of production (MAPA, 2013). Through a set of techniques and tools, it is possible to optimize rural property management, involving all cultivation and use of agricultural inputs, providing maximum economic efficiency, mainly related to savings in the use of inputs (FOUNTAS *et al*., 2005; TAMIRAT *et al*., 2018).

However, the PF can be considered as a “tool kit” available for the farmer to choose what he considers necessary and, although it is still important to better specify which technologies are contained in the PF package, they can be classified into three large groups: data collection, remote sensing and decision-making technologies (LOWENBERG-DEBOER; ERICKSON, 2019)

In traditional agriculture, it is common to use a “whole field” approach, where the farm is considered a homogeneous area and decisions are made based on field averages. In this way, the application of inputs occurs uniformly throughout the area (GRISSO *et al*., 2009).

In PF, the focus is on managing the spatial variability of production areas, as well as all other factors involved, with the use of technologies that have been adapted for the agricultural environment (CIRANI; MORAES, 2011). Variations are observed between the so-called "management zones", based on indices such as soil pH, yield rates and pest infestation, in addition to other factors that may affect production (GRISSO *et al*., 2009).

The emergence of PF occurred from the need to manage spatial variability, taking into account that the area cultivated in a crop varies in its composition, reflecting in the same way the variation in production, regardless of the size of the area (MOLIN *et al*., 2015). The first recommendation for acidity tests on soils sampled on a grid for applying limestone was recorded in a bulletin from the Illinois experimental field, in the United States, by Linsley and Bauer in 1929. According to the literature, this is the oldest record that the variability spatial area of farming began to be taken into account (INAMASU; BERNARDI, 2014).

Until the end of 1989, research in PF was concentrated on the development of sensors, evolving from then on, with the availability of the use of Global Positioning Satellites (GPS) (MANTOVANI; GOMIDE, 2000). In general, the large research centers in agricultural engineering and technology intensified work on the development of PF (MANTOVANI; GOMIDE, 2000) and in 1996, the first harvesters appeared with the capacity to map production, which boosted PF in the world (INAMASU; BERNARDI, 2014), making it possible to apply inputs at variable rates, using machines, no longer doing so homogeneously (ANTONINI *et al*. 2018; INAMASU *et al*., 2011).



Currently, there is a large number of industries that manufacture machines and control systems and companies specialized in developing software for integration between PF equipment (MANTOVANI; GOMIDE, 2000). Through PF equipment, data is collected to help farmers make decisions, which mainly involve defining fertilizer and pesticide application rates, seed distribution densities, irrigation application rates and cropping regimes (DABERKOW; MCBRIDE, 1998).

Improved field verification methods, including soil analyses, aerial photographs and crop recognition, have enabled a better perception of the variability of soil characteristics and crops in the field. As a result, one can realize the potential benefits of managing crops by zones within fields rather than entire fields to increase profitability and environmental protection (ROBERT, 2002).

Molin (2002) and Swinton and Lowenberg-Deboer (2001) give PF a more systemic definition, defining it as a new form of agricultural production management, which involves a set of technologies and procedures, used not only for the treatment of the spatial variability of the crop, but also for the optimization of all factors involved.

In this way, it can be said that PF is not just the addition of new technologies, but rather an information revolution, made possible through these technologies that result in a higher level, generating as a result a more accurate agricultural management system (ROBERT, 2002) which contributes to the improvement of management of both production and rural property (MAPA, 2013), being an important tool for optimizing agricultural activity (FERRAZ *et al.*, 2011 ). Additionally, PF promotes multiple benefits for producers, consumers and the environment (TAMIRAT *et al*., 2018).

Costa and Burnquist (2014) explains that the objective of using PF to replace conventional techniques is to obtain the following results: (a) cost reduction through savings in the use of inputs; (b) increased agricultural productivity through more efficient application of inputs; and (c) reduction in water and environmental pollution.

Additionally, the PF provides important information for the farmer to record the history of his activity over time, improve decision-making, encourage greater traceability, generate better results in the marketing of products, in addition to fostering relationships between owners and tenants, among other benefits (McBRATNEY *et al.*, 2005).

Currently, the main tools used in PF for grain cultivation are: application maps, georeferencing , Geographic Information Systems (GIS), Global Positioning System (GPS) , Autopilot, Variable Rate Technology (VRT) (equipment that allows the application of fertilizers at a variable rate) and Precision Irrigation, RTK Base (Real Time Kinematic), Scouting, Remote Sensing, Productivity Map and Harvest Monitor (ANTOLINI, 2015).



## METHODOLOGICAL PROCEDURES

When constructing a scientific paper, researchers must clearly understand the problem they want to study. When developing a research project, they must clearly understand the question they want to answer, have clearly defined objectives, and plan the data collection and analysis. Thus, a literature review provides the opportunity to advance knowledge on the subject. It demonstrates what authors have been writing on the subject and what has not yet been explored (FERENHOF; FERNANDES, 2016; ECHER, 2001).

This study aimed to quantitatively and qualitatively analyze the scientific production developed on the PF issue. Therefore, we directed searches on online research platforms to locate studies whose focus fits this study's scope.

The searching and mapping process of the scientific production should be anchored in techniques such as systematic review, content analysis, and bibliometry. In addition to assisting in the scientific community's investigation process, these techniques allow the identification of possibilities for developing studies that have not yet been explored (COOK *et al.*, 1997; BARDIN, 2010; ECHER, 2001).

The bibliometric review quantitatively studies the publications. Statistical analysis can study document use and creation characteristics, showing the most relevant aspects (SPINAK, 1998). In turn, a systematic review can locate and synthesize the research through organized procedures that allow the replication of each step of the process and avoid possible researcher biases (LITTELL *et al.*, 2008; FERENHOF; FERNANDES, 2016).

Meanwhile, content analysis comprises a set of techniques for analyzing communications. It is divided into three phases: (1) pre-analysis; (2) material exploration; (3) treatment of results, inference, and interpretation (BARDIN, 2011).

In an effort to systematize the literature search workflow, Ferenhof and Fernandes (2016) developed, based on the six principles of systematic review proposed by Jesson, Matheson, and Lacey (2011), the **SSF** (*Systematic Search Flow*) method. This method establishes a literature review development methodology based on four steps.



Therefore, the first step in developing a systematic review involves defining the protocol, which is a set of rules comprising five activities: (1) selecting the keywords to be searched; (2) consulting databases; (3) organizing the bibliography; (4) standardizing the selection; and (5) composing the portfolio of articles, in addition to defining the criteria for filtering the results (FERENHOF; FERNANDES, 2016).

The second step includes analyzing the studies and consolidating them, where data on the published journals, most cited authors, and the year with the highest number of publications, among others, are combined. The third stage describes the conclusions, deductions, and inferences regarding the material studied. Then, the fourth stage produces scientific writing (FERENHOF; FERNANDES, 2016).

## RESEARCH SAMPLE

### Searches in scientific publication databases

This study defined the *Web of Science* and *Scopus* databases to search for the desired content. The choice considered the importance of searching for studies published in international journals of high relevance and significant impact on the scientific community.

The keyword combinations defined for the searches (topics) were "*precision agriculture*" and "*adoption*" and "*precision farming*" and "*adoption*". In an effort to broaden the results as much as possible, we did not establish category filters. However, we defined filters to delimit the results by publication type (articles only), language (English and Portuguese), and year of publication (from 2017 to 2022).

The first search on the *Scopus* platform, using the descriptors "*precision farming*" *AND* "*adoption*" resulted in 165 publications. When filtering for "only the last five years", we obtained 80 publications. When filtering for "articles only", we obtained 51 studies. When selecting only those written in "English and Portuguese", we obtained 49 studies.

In the second search, using the keyword combination *"precision agriculture" AND "adoption"*, we obtained 489 publications. We removed those prior to 2017, which resulted in 291 publications. When filtering these to "articles only", we obtained 188 studies. When filtering for only those written in "English and Portuguese", we obtained 187 studies.

The first search conducted on the *Web of Science* platform, using the descriptors "*precision farming*" AND "*adoption*" resulted in 126 publications. When filtering for "only the last five years", we obtained 69 publications. When filtering for "articles only", we obtained 56 studies. When selecting only those written in "English and Portuguese", we obtained 50 studies.



In the second search, using the keyword combination "*precision agriculture*" AND "*adoption*", we obtained 427 publications. We removed those prior to 2017, which resulted in 275 publications. When filtering these to "articles only", we obtained 204 studies. When filtering for only those written in "English and Portuguese", we obtained 200 studies. Chart 1 summarizes the article selection process.

**Chart 1 - Article portfolio selection steps**

| Descriptors | | | Publications from the last 5 years | Articles Only | Languages: English and Portuguese |
|---|---|---|---|---|---|
| **Scopus** | | | | | |
| **Search 01** | "*precision farming*" and "*adoption*" | 165 | 80 | 51 | 49 |
| **Search 02** | *"precision agriculture"* and *"adoption"* | 489 | 291 | 188 | 187 |
| **Web Of Science** | | | | | |
| **Search 01** | "*precision farming*" and "*adoption*" | 126 | 69 | 56 | 50 |
| **Search 02** | *"precision agriculture"* and *"adoption"* | 427 | 275 | 204 | 200 |
| **TOTAL** | | **1,207** | **715** | **499** | **486** |

Source: Own preparation.

The results found in each of the searches were exported using a BibTex file and imported into the *StArt (State of the Art Through Systematic Review*) tool developed by the Software Engineering Research Laboratory (LaPES) of the Department of Computer Science of the Universidade Federal de São Carlos (UFSCar).

We excluded duplicate studies using the StArt tool, which resulted in 289 studies. Then, these studies underwent simplified content analysis. This process consisted of reading the abstracts to select only those studies that specifically dealt with PF adoption.

This step required defining the protocol for classifying the studies according to the **SSF** (*Systematic Search Flow*) methodology proposed by Ferenhof and Fernandes (2016). The protocol definition is of utmost importance for classifying articles. It standardizes the process and ensures the review's replicability (FERENHOF; FERNANDES, 2016). The protocol determined three exclusion criteria: (i) systematic reviews, literature reviews, and bibliometric reviews; (ii) not having access to the full text of the article; (iii) technologies in general (smart agriculture, 4.0 technologies, Internet of Things, etc.).

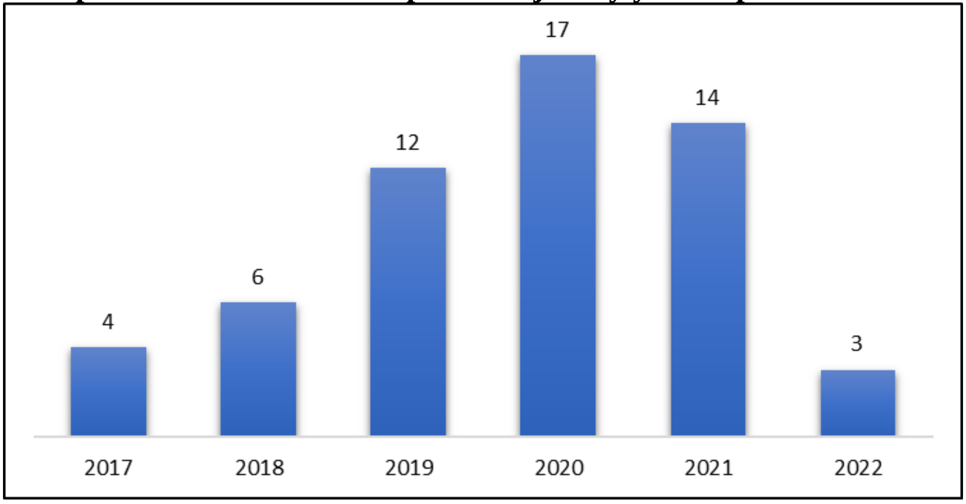
This content analysis removed studies on farming technical issues (crop, soil, nutrients, inputs, production practices, production efficiency), financial and economic analysis, bibliometric articles, and systematic reviews. Moreover, we excluded studies associating the PF theme with others related to technology, such as farming 4.0, the Internet of Things, artificial intelligence, etc. This analysis excluded 233 studies. The remaining 55 studies made up the portfolio for the bibliometric analysis. 291

## RESULTS PRESENTATION AND DISCUSSION

### Bibliometric analysis of the articles

We mapped the studies selected in the previous step using the bibliometric approach techniques. Graphic 1 shows that the largest number of publications dealing with the PF adoption subject occurred in 2019, 2020, and 2021. The largest publication volume occurred in 2020, accounting for 30% of the selected studies. The second was 2021, accounting for 21% of the selected studies.

**Graphic 1 - Chart demonstrating the studies published on the PF adoption subject by year of publication**




Source: Own preparation. Web of Sciences and Scopus databases (2022).

Moreover, in 2019, 2020, and 2021, the publications on this theme grew more than twice as much as in 2018 and 2017, which shows the theme's relevance and timeliness. Identifying the frequency in which studies are cited indicates the study's relevance to the scientific community. Table 1 shows the list of studies with more than 20 citations. From a total of 57 studies, 13 were the most cited, representing 20% of the total sample. The most cited study was "*Precision agriculture technology adoption: a qualitative study of small-scale commercial "family farms" located in the North China Plain*", with 91 citations, followed by Barnes *et al.* (2019) "*Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers*", which was cited 76 times.



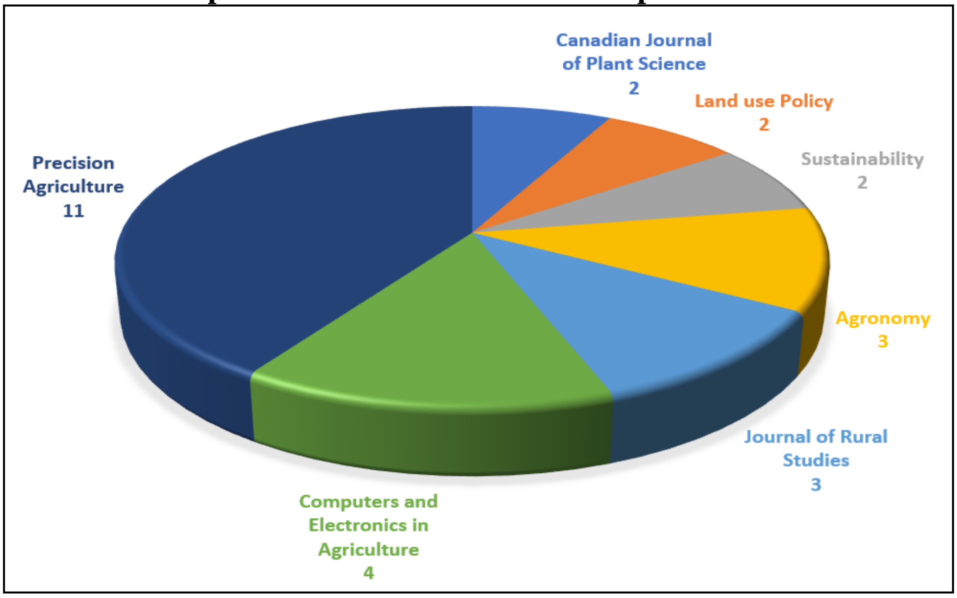
**Table 1 - List of the most cited articles**

| Title | Citations |
|---|---|
| Precision agriculture technology adoption: a qualitative study of small-scale commercial family farms {''} located in the North China Plain | 91 |
| Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers | 76 |
| Adoption of precision agriculture technologies by German crop farmers | 73 |
| Ordering adoption: Materiality, knowledge and farmer engagement with precision agriculture Technologies | 66 |
| Influencing factors and incentives on the intention to adopt precision agricultural technologies within arable farming systems | 39 |
| From precision agriculture to Industry 4.0 Unveiling technological connections in the agrifood sector | 36 |
| Event dependence and heterogeneity in the adoption of precision farming technologies: A case of US cotton production | 32 |
| Is the trend your friend? An analysis of technology 4.0 investment decisions in agricultural SMEs | 30 |
| Farm and operator characteristics affecting adoption of precision agriculture in Denmark and Germany | 29 |
| Adoption of Precision Farming Tools: The Case of Italian Farmers | 28 |
| Farmer perceptions of precision agriculture technology benefits | 24 |
| Farm adoption of embodied knowledge and information intensive precision agriculture technology bundles | 23 |

Source: Own preparation. Web of Sciences and Scopus databases (2022).

Another relevant data in mapping scientific production is to know in which journal each study is published. The article sample is distributed across 36 different international journals. Two journals stand out, accounting for 27% of the analyzed studies. The *Journal Precision Agriculture*, with 11 published studies (20%), and the *Journal Computers and Electronics in Agriculture*, with four published studies (7%). Graphic 2 shows the seven journals with the highest number of publications.

**Graphic 2 - Journals with the most publications**




Source: Own preparation. Web of Science and Scopus databases (2022).



The mapping of the places where research on the subject is being carried out is of great relevance to this review. Map 1 demonstrates the countries where PF research has been most recurrent. The US leads the list of countries with the most studies on PF adoption, with 14 publications, or 25% of the total analyzed papers. Germany and Italy follow, with 9 and 6 studies, respectively.

**Figure 1 - Map of most surveyed countries**


Source: Own preparation. Web of Science and Scopus databases (2022).

The selected studies come from 15 countries. Some studies investigated PF use in more than one country. Table 2 shows the number of studies published in each country included in the analyzed sample.

**Table 2 - Countries hosting the surveys**

| Researched Country | Qty. Articles | % of total |
|---|---|---|
| United States | 14 | 25% |
| Germany | 9 | 16% |
| Italy | 6 | 11% |
| Canada | 5 | 9% |
| Brazil | 4 | 7% |
| China | 3 | 5% |
| India | 3 | 5% |
| Greece | 3 | 5% |
| Iran | 2 | 4% |
| Argentina | 2 | 4% |
| Ghana | 2 | 4% |
| Belgium | 2 | 4% |
| Netherlands | 2 | 4% |
| United Kingdom | 2 | 4% |
| Hungary | 1 | 2% |
| France | 1 | 2% |
| Switzerland | 1 | 2% |
| Austria | 1 | 2% |
| Denmark | 1 | 2% |

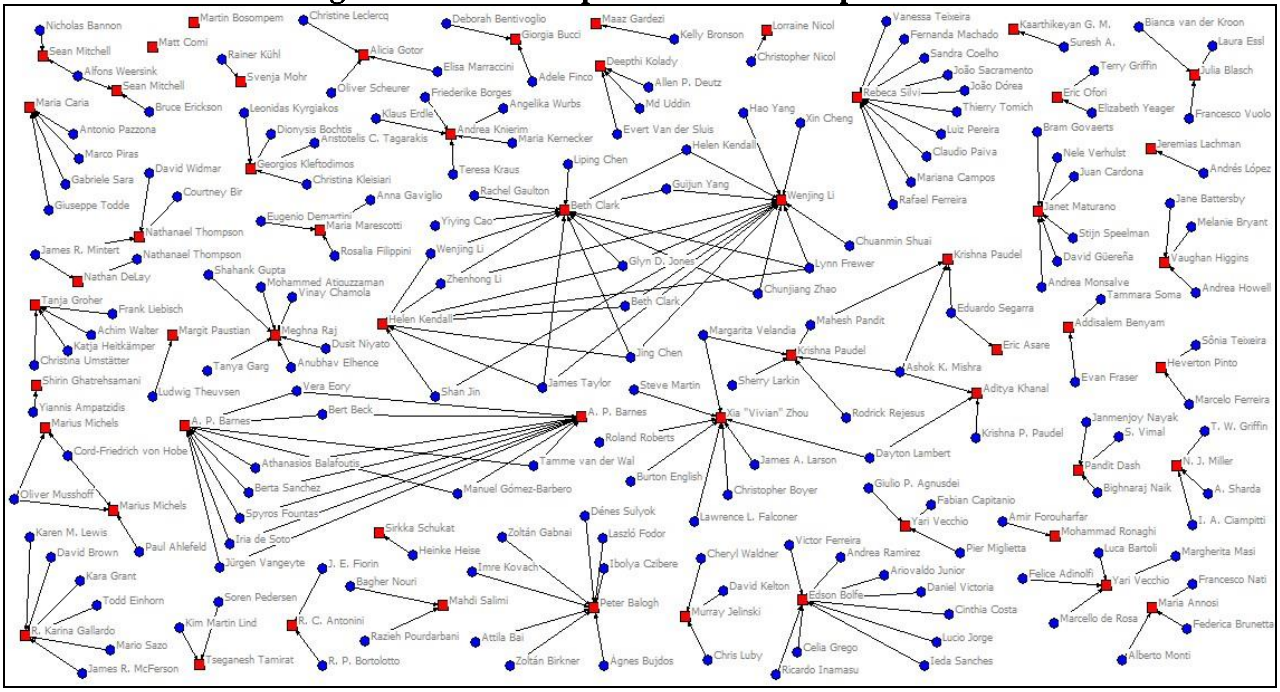
Source: Own preparation. Web of Science and Scopus database (2022).

Figure 1 shows the authorship and co-authorship network of the selected studies. The Ucinet software graphically demonstrated the relationships between authors and coauthors. The little red squares represent the authors, while the little blue circles represent the co-authors.

Martin Bosompem and Matt Comi published alone, ten authors published in pairs, and another 11 authors conducted their research with two co-authors. The remaining 32 authors comprised three or more co-authors.

There are two major networks of studies involving the subject. The first network, smaller in size, includes the work of authors Aditya R. Khanal, Krishna P. Paudel, Eric Asare, and Xia “Vivian” Zhou and has 14 co-authors. In addition to authoring two articles in this network, Krishna P. Paudel co-authored Aditya R. Khanal.

**Figure 2 - Authorship and co-authorship network**




Source: Own preparation.

The co-authors who worked with more than one author: Dayton M. Lambert, a co-author on the studies by Aditya R. Khanal and Xia "Vivian" Zhou; Margarita Velandia, a co-author on the studies by Xia "Vivian" Zhou and Krishna P. Paudel; Ashok K. Mishra, a co-author on two studies by Krishna P. Paudel and a study by Aditya R. Khanal; and Eduardo Segarra, a co-author on the studies by Eric Asare and Krishna P. Paudel.

The second network includes authors Bert Clark, Wenjing Li, Helen Kendall, and 17 co-authors. Chunjiang Zhao co-authored the works of Bert Clark and Wenjing Li, and the latter co-authored the research of Helen Kendall and Bert Beck. James Taylor co-authored all three authors' papers, as did Glyn D. Jones, Lynn Frewer Zhenhong Li, and Jing Chen. Beth Clark co-authored Helen Kendall's research.

Author A. P. Barnes produced two articles with the same group of co-authors. Sean Mitchell and Maria Michels produced two articles with different co-authors. We have identified another small network containing two authors, Nathanael Thompson and Nathan Delay, and four co-authors.

The word frequency analysis is also relevant. Figure 2 shows the Word Cloud image, which illustrates the most used keywords in the analyzed articles. The size of each word highlights the frequency with which it appears. The larger the word, the more times the term was used. Most relevant words include: *Agriculture*, *Precision*, *Technology*, *Adoption*, and *Farming.*

**Figure 2 - Word cloud**


Source: Own preparation.

## Content analysis

After reading each of the 56 articles selected for the bibliometric analysis, we excluded the studies that were not following the protocol defined according to the SSF method (FERENHOF; FERNANDES, 2016). As a result, 26 articles were submitted for in-depth content analysis, which this section will present.

The selected studies dealt with the factors influencing PF adoption and were carried out through field research to collect data directly from farmers, providing their perception regarding adopting this type of technology.

The PF concept has always been related to technology development (ROBERT, 2002). We could see that the term "precision farming" is commonly presented as part of larger concepts such as smart agriculture, 4.0 technologies, and the Internet of Things. We have maintained the studies by Annosi *et al.* (2019), Ronaghi and Forouharfar (2020), and Bolfe *et al.* (2020) because they address PF in the context of these new terminologies, which makes them relevant to this study. Annosi *et al.* (2019) investigate the adoption of 4.0 technologies in a managerial decision context, suggesting that "managerial accumulation of knowledge regarding technologies should enable firms' response to technical change and investment allocation in 4.0 technology investment". Their results proved it. They showed that the decision on technology adoption directly relates to the manager's ability to search for evidence on the use of technologies and the manager's perceived usefulness regarding these technologies.

Li *et al.* (2020) and Ronaghi and Forouharfar (2020) found similar results. They based their studies on the Unified Theory of Acceptance and Use of Technology (UTAUT).

Vecchio *et al.* (2020) performed cluster analysis to understand PF adoption. Three different clusters were identified in their work. The first group, referred to as “non-adopters”, included farmers from small farms with little exposure to technology and low labor intensity. The second group, referred to as “technology adopters”, included farmers with large land areas, 8-hour technology exposure levels, high education levels, and young people. The third group, those inclined to adopt, included farmers owning farms with medium exposure levels (4 to 8 hours) and medium daily work intensity.

Results indicated that farming practices have a relevant effect on the decision to adopt new technologies. Farmers with longer exposure to technologies are more likely to adopt new tools.

Balog *et al.* (2021) used cluster analysis in studies conducted in Hungary. Results showed that farmers willing to use PF, or already using it, were those from medium-sized farms, medium income, and medium efficiency, with education levels ranging from high school to university. However, this group was not satisfied with the information flow they have access to, and they rate the PF's socioeconomic usefulness as extremely low.



Meanwhile, even though they have the necessary information to invest in PF, farmers with large areas have no interest in initiating the second phase of technological change. This lack of interest is partly due to a lack of vision of the benefits of sustainability. Furthermore, although large farms have high technological levels, much of this technology does not include precision tools. Thus, these farmers perceive that investing in more PF tools would generate a significant investment with inadequate returns (BALOGH *et al.*, 2021).

Ronaghi and Forouharfar (2020) analyzed the factors influencing PF adoption using the Unified Theory of Acceptance and Use of Technology (UTAUT) model. The study aimed to understand whether there is a relationship between farmers' intention to use IoT (Internet of Things) technology and smart agriculture implementation. Results showed that expectations regarding the technologies' performance and the convenience and ease of use directly influence the decision to adopt technologies in agriculture.

Perception regarding technology utility, perceived benefits, and performance expectation from technology adoption were points highlighted as responsible for causing positive impact by Annosi *et al.* (2019), Li *et al.* (2020), and Ronaghi and Forouharfar (2020) in their studies.

According to Annosi *et al.* (2019), such perceptions even override the importance over economic or cost-benefit concerns. Salimi *et al.* (2020) studied the main factors of the Davis model in the acceptance of agricultural automation. They observed a significant relationship between the intention to use and the actual use of the technologies. They concluded that when there is a positive perception of usefulness, there is a greater tendency to adopt such technologies.

Exposure to technology and the availability of technical communication structure positively influence the adoption of PF technologies (PINTO *et al.*, 2017; KOLADY *et al.*, 2021; PAUDEL *et al.*, 2021; VECCHIO *et al.*, 2020). Producers using computers for farm management are more likely to adopt technologies soon after they become available (PAUDEL *et al.* 2021; KOLADY *et al.*, 2021). Thus, the rural enterprise's technological level can favor or disfavor adoption since farmers unfamiliar with some technologies may perceive them as complex and tend not to adopt them (BLASCH *et al.*, 2021).

The technologies already used by farmers can predict their behavior, and the acquired experience creates a security that induces them to stick to their technology packages. Risk aversion may be the main determinant of this characteristic since information and assistance to farmers for innovations is slower than technological advancement (MILLER *et al.*, 2019; THOMPSON *et al.*, 2019).

The way the farmer understands the result of using a certain technology can change according to the analyzed perspective. For example, when the producer is asked about yield improvement, PF can mean increased profitability and improved management. On the other hand, if compelled to look from the convenience perspective, producers were more likely to perceive PF as an obstacle to their work as farm managers (THOMPSON *et al.*, 2019).



Producers' resistance to adopting new technologies may have its origin in the lack of training. Access to knowledge and consulting services, participation in cooperation networks, and technical assistance and training programs are important issues in fostering technology use (PINTO *et al*, 2017; ASARE; SEGARRA, 2018; BLASCH *et al.*, 2021; GROHER *et al.*, 2020; LI *et al.*, 2020). Furthermore, producers who receive information from university publications are more likely to adopt new technologies (ASARE; SEGARRA, 2018; PAUDEL *et al.*, 2021).

The farmers' education level is another important factor to consider in studies on PF adoption. Farmers with higher levels of education have more information regarding the benefits of adopting technologies. Meanwhile, untrained farmers with low education levels are likely to adopt PF practices to a lesser extent due to adaptation difficulties or because they are not fully aware of the positive socioeconomic utility of PF (BALOGH *et al.*, 2021; BARNES *et al.*, 2019b; GROHER *et al.*, 2020; LI *et al.*, 2020; VECCHIO *et al.*, 2020)

On the other hand, the results of the studies by Tamirat, Pedersen, and Lind (2018), conducted with farmers in Germany and Denmark, identified that education level, awareness of the topic, and availability of information are not directly related to a greater chance of adoption, but rather, other factors, such as the size of the cultivated area, for example.

Paudel *et al.* (2020) evidence that more educated and experienced farmers, who perform farm planning, choose to use PF because they know the benefits generated in terms of profitability. Kolady *et al.* (2021) found the same result. In this case, the farmers' experience refers to their time in business. Vecchio *et al.* (2020) found a controversial result on this variable. They identified that more experienced farmers feel less need to invest in emerging technologies.

Furthermore, Paustian and Theuvsen (2017) found the influence of farmer experience on PF adoption in their study of German farmers. They identified that adoption increases when the farmers' experience exceeds 16 years or is less than five years. Thus, they evidenced two important profiles, the experienced and the young ICT (Information and Communication Technology) users and likely successors of the business. Moreover, they concluded that, for these two groups, the economic advantages generated by using PF might outweigh the adoption costs.

The age factor was another characteristic studied in the technology adoption context, and although it may have a close relationship with the experience variable, they need to be analyzed separately. Paustian and Theuvsend (2017) and Tamirat, Pedersen, and Lind (2018) found no significant age effect on PF adoption. Younger farmers are more likely to adopt PF technologies because they are more familiar with technologies. In addition, they are qualified and motivated to engage in the activity (ANTONINI *et al.*, 2018; PAUDEL *et al.*, 2020; PAUSTIAN; THEUVSEN, 2017). In contrast, increasing age is a contributing factor to not adopting technologies (VECCHIO *et al.*, 2020).

One of the factors identified in most of the analyzed research concerns the cost of PF investment. Annosi *et al.* (2019) identified other more relevant variables in farmers' decision to invest in technology, such as cognitive and environmental aspects. However, most farmers are concerned with cost-benefit and return on investment when adopting new technologies. The high cost of training (BALOGH *et al.*, 2021) and investment in new technologies still figures as a major limiting factor to adoption (BARNES *et al.*, 2019a, 2019b; BLASCH *et al.*, 2021; KAARTHIKEYAN; SURESH, 2019; MILLER *et al.*, 2019; NICOL; NICOL, 2018).

Even though the cultivated area size may seem a great predictor of new technology adoption, the intention to innovate using PF tools does not directly relate to the cultivated area size (BALOGH *et al.*, 2021). Technology acceptance partially depends on other factors, such as the region or the technology's focus (BARNES *et al.*, 2019b).

Considering that small and medium-sized farmers have a limited-sized area, Antonini *et al.* (2018) concluded they are more likely to adopt PF because of the need to produce more. They cited that all the interviewed farmers cultivated at least 30 hectares of land. They conducted the study in the Northwest region of the state of Rio Grande do Sul.

Kolady *et al.* (2021), Maturano *et al.* (2021), Blasch *et al.* (2021), and Kaarthikeyan and Suresh (2019) found evidence that the vast majority of farms adopting technologies are those with larger areas, which is possibly due to the greater need for management organization (THOMPSON *et al.*, 2019).

In the environmental context, many farmers have chosen to use PF techniques and tools to save inputs and decrease environmental impacts (ANNOSI *et al.*, 2019; BLASCH *et al.*, 2021; BOLFE *et al.*, 2020; NICOL; NICOL, 2018). However, some producers are still unaware of the real benefits that adopting PF can generate to the environment (KENDALL *et al.*, 2021).

**FINAL REMARKS**

This study aimed to identify the state of the art of publications on PF and investigate the methods, locations, and types of studies conducted to understand farmers' perceptions regarding adopting PF tools.

Using bibliometric analysis, the study met the objective proposed in the quantitative approach. It mapped the countries with the most studies on the subject, identifying the most frequently used terms, the periods with the highest rates of research, and the knowledge network formed over the period studied (from 2017 to 2022).



Through the graphical demonstration of the authorship and co-authorship network, we pointed out two large research groups dedicated to studying PF adoption, which combined have 33 researchers. Furthermore, we identified other small groups of four and five people. The fact that there are large groups of researchers involved in specific research allows for greater coverage regarding the number of interviewees, which broadens the research and provides for greater result dissemination.

The content analysis enabled meeting the proposed objective's qualitative approach. Reading through the full text of each of the 29 selected articles provided the most important information. After the analysis, we found that only three articles used some theory as a basis for understanding PF adoption. One study was based on the *Technology Acceptance Model* (TAM), known as the *acceptance* model of technology by Davis. Two surveys aimed to explain adoption based on the Unified Theory of Acceptance and Use of Technology (UTAUT), created by Venkatesh *et al.* (2003).

The other studies were not anchored in any specific theory. However, they used different methodologies to analyze the collected data. Most studies structured the questionnaires in a similar conceptual framework, grouping economic, demographic, and social characteristics.

The studies have shown great heterogeneity in PF technology adoption. It became evident that the technology's high cost is still the main barrier, which is directly related to the property's size and income obtained. Uncertainty over risk also prevents many producers from investing in PF.

Actions encouraging adoption related to increasing farmers' information regarding the benefits of adopting PF were mentioned as a key to boosting technology use in agriculture. The lack of knowledge can often generate insecurity on the part of farmers, especially the more experienced ones. They prefer to rely on their *know-how* rather than invest in technologies they know little about.

The studies carried out in Brazil have identified that the main benefits sought by the producers relate to the increase in productivity and profitability. Adopting new technology is conditioned to the property's technical structure, and the high cost of the equipment is still the biggest barrier. Farmers' involvement in information networks such as cooperatives is important in increasing technology investments.

Future studies can aim to understand farmers' perceptions regarding PF's contribution to reducing environmental impacts. Unfortunately, the perception of profitability and return on investment always seems ahead of the concern for environmental benefits. The increase in research in this area can generate a flow of important information to make real changes happen, whether by the farmers themselves or through government incentives.



Even outside Brazil, in countries like the United States, Italy, and Germany, where most of the studies were identified, the importance of PF as a tool to reduce environmental impacts still does not encourage farmers to use PF. Government policies to encourage environmental preservation can encourage adoption (ASARE; SEGARRA, 2018).

Moreover, we suggest studies with different article inclusion and exclusion criteria. For example, one could map the perceptions of professionals from equipment suppliers and technical assistance networks, which would complement this study. Furthermore, studies can include searches with other descriptors and in different databases, which were not used for selecting articles in this study.

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